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ANNUAL REPORT

Detecting Small-Scale Topographic Changes and Relict Geomorphic Features on Barrier Islands Using SAR

Year 1

James C. Gibeaut,* K. Clint Slatton,** Melba M. Crawford,** and Roberto Gutierrez*

Prepared for the National Atmospheric and Space Administration (NASA)
Office of Mission to Planet Earth
Topography and Surface Change Program

NASA Grant No. NAG 5-2954

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Noel Tyler, Director
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**Center for Space Research
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Appendices (attached)

Introduction

The shapes and elevations of barrier islands may change dramatically over a short period of time such as during a storm. Even between storms, sediment is constantly shifting to and from these islands and between different areas of the islands at varying rates and in varying amounts. Coastal scientists and engineers, however, are currently unable to measure these changes occurring over an entire barrier island at once. This three-year project, which is funded by NASA and jointly conducted by the Bureau of Economic Geology and the Center for Space Research at The University of Texas at Austin, is designed to overcome this problem by developing the use of interferometry from airborne synthetic aperture radar (AIRSAR) to detect changes in coastal topography. Surrogate measures of topography observed in fully polarimetric AIRSAR are also being investigated.

Topographic changes on Galveston Island and Bolivar Peninsula, Texas (Fig. 1) detected by Topographic SAR (TOPSAR) and AIRSAR will be compared with changes measured by Global Positioning System (GPS) ground surveys. At least three sets of TOPSAR and AIRSAR data will be compared to detect changes during 1995, 1996, and 1997, and we will relate these changes to meteorological and wave conditions. In addition to topographic mapping, this project is evaluating the use of AIRSAR to detect old features such as storm scarps, storm channels, former tidal inlets, and beach ridges that have been obscured by vegetation, erosion, deposition, and artificial filling. We have also expanded the work from the original proposal to include the mapping of coastal wetland vegetation and depositional environments. Methods developed during this project will provide coastal geologists with an unprecedented tool for detecting and understanding sedimentological changes. This understanding will improve overall coastal management policies and will help reduce the effects of natural and man-induced coastal hazards. This report summarizes our accomplishments during the first year of the study. Also included is a discussion of our planned activities for year 2 and a revised budget.

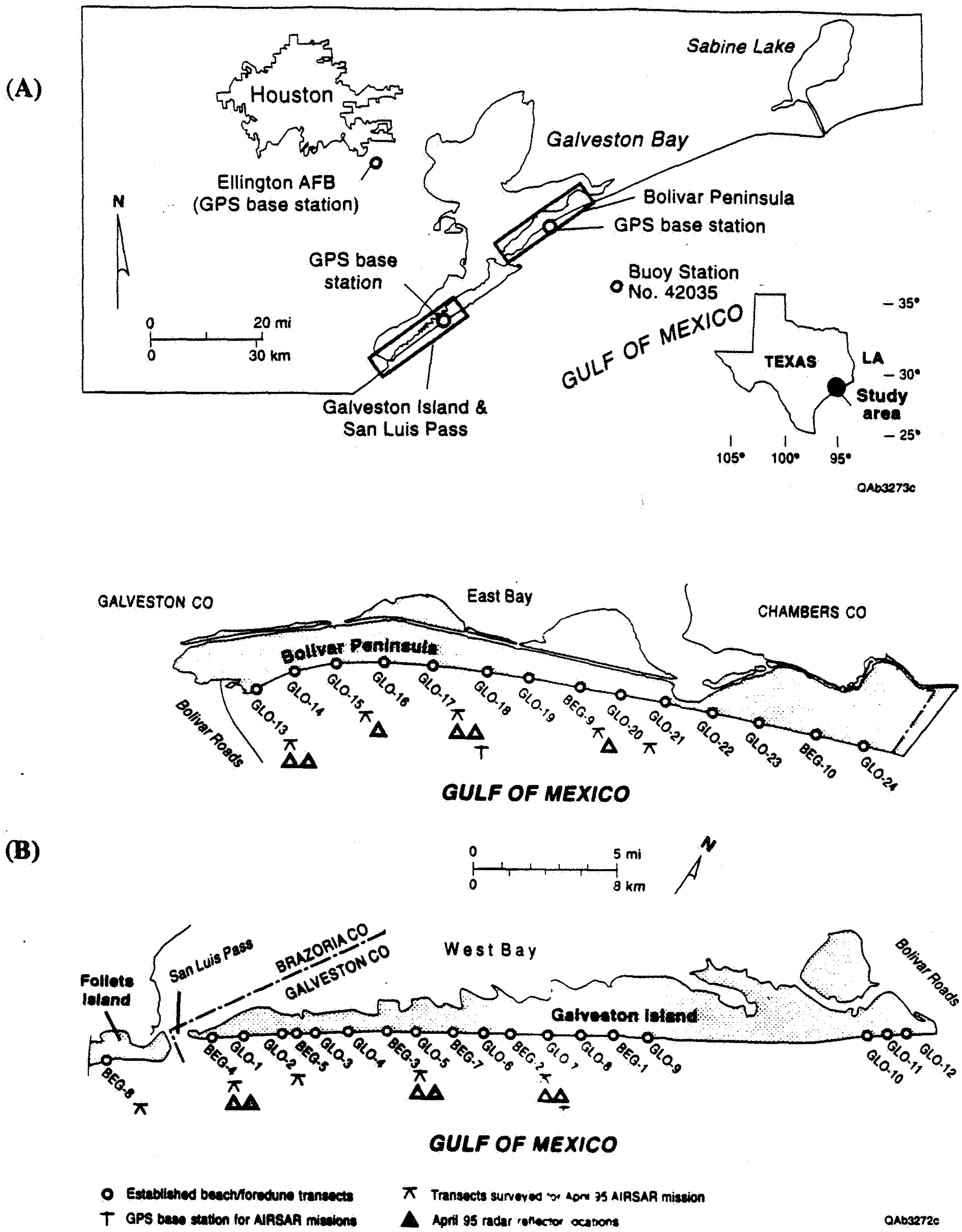

Figure 1. Study areas for April 28 and 29, 1995, AIRSAR missions. **(A)** Locations of study areas on Galveston Island and Bolivar Peninsula. Also shown are GPS base stations operated during the flights. The NASA DC-8 aircraft took off from Ellington Airforce Base for each flight. Buoy Station No. 42035 is operated continuously by the National Data Buoy Center and provides wave and meteorological data. **(B)** Detail of study areas.

April 1995 AIRSAR Mission

We successfully completed our first AIRSAR missions on April 28 and 29, 1995. During both flights, we operated two geodetic-quality GPS base stations on the ground and one on the DC-8 aircraft (Fig. 1). Just before the flight, we placed and surveyed twelve radar reflectors along two, 30-km flight lines to aid with image registration and correction. Within 2 days of the mission, we completed detailed GPS surveys of a 2-km stretch of beach on Galveston Island and additional GPS surveys along 10 transects over the study area (Fig. 1). These ground surveys are required to check the TOPSAR topographic solutions.

AIRSAR data were acquired over Galveston Island on April 28, 1995, and over Bolivar Peninsula on April 29, 1995. For each area, we collected two passes with front and back looks of C- and L-band TOPSAR data operating in 40-MHz mode and one pass of C-, L-, and P-band fully polarimetric AIRSAR data operating in 20-MHz mode. For these missions, we constructed 12 radar reflectors from angle stock and sheet metal. They are corner reflectors 1 m in size, and they show well in the C- and L-band imagery.

Data

Status of the Data

(1) We have received almost 50 percent of the processed 20-MHz, polarimetric AIRSAR data that was acquired over the study area in April 1995. We do not yet have any of the 40-MHz TOPSAR data, which is to be provided by NASA.

(2) We have all the kinematic GPS data taken on the ground during the missions and are acquiring the data taken on the aircraft from NASA.

(3) We have acquired and reduced all ground survey data taken by us during the missions, and we have transmitted the X,Y,Z positions of the radar reflectors for the Galveston area to the Jet Propulsion Laboratory (JPL). In addition to the topographic data we collected, we have obtained topographic transect data of Bolivar Peninsula taken by a commercial surveyor in 1992.

(4) We have acquired digital data of roads and hydrography and have entered the data into our Geographic Information System.

(5) We acquired one high-quality vertical aerial photograph of Bolivar Peninsula taken at 1:40,000 scale by the U.S. Geological Survey.

Data Analysis

We have reduced and compiled all topographic survey data acquired by us on the ground during the missions. We have also digitized the commercial transect data from Bolivar Peninsula mentioned previously. We have transmitted the X,Y,Z positions of the radar reflectors for the Galveston area to the JPL. The JPL intends to use our area and radar reflector positions to test the TOPSAR processor. We are awaiting the acquisition of the GPS data taken on the aircraft to obtain kinematic solutions of the aircraft's position during the flights.

We have purchased and installed the software packages PCI and ENVI, which are capable of performing preliminary analysis of radar data. We are also developing our own software for repeat-pass interferometry and for modeling backscatter from wetland vegetation. We have made two workstations available to the project and a four-gigabyte disk drive available to store and process radar data.

We have conducted preliminary analyses of one scene of polarimetric data from Bolivar Peninsula using the aforementioned software and have conducted qualitative analysis of most of the polarimetric data from Bolivar and Galveston. We have also used combinations of radar backscattering data to form indices that are sensitive to the physical characteristics of the surface and vegetation. These indices allow us to qualitatively determine the relative importance of microwave scattering from the surface and from the vegetation in the different environments.

Preliminary Results

Because we have yet to obtain TOPSAR data, we have focused on the polarimetric data during the past year. We have presented our preliminary work at two meetings (Geological Society of America, South-Central Section Meeting, and the Sixth Annual

JPL Airborne Earth Science Workshop) and have submitted one abstract and a paper to the 1996 International Geoscience and Remote Sensing Symposium (IGARSS) and an abstract to the spring 1996 American Geophysical Union (AGU) meeting. These abstracts and paper are appendices in this report. Below is a summary of our current findings.

The study areas on Galveston Island and Bolivar Peninsula have a relief of less than 4 m and are composed of distinct subenvironments and morphological features. These subenvironments and features include multiple beach ridges and swales, vegetated barrier flats, foredunes, high- and low-salt-water marshes, intertidal/wind-tidal flats, tidal creeks, tidal deltas, and exposed and sheltered beaches. Also present are relict washover fan/flood-tidal delta complexes. Salinity, vegetation, sediment/soil type, and surface roughness vary significantly between these areas. Beach ridges have dry, shelly sand sediment, and intervening swales between ridges are wetter with some having standing water. Barrier flats are also made of shelly sand and support land uses such as agriculture, ranching, and urban/recreational development. Sediments forming salt-water marshes and intertidal/wind-tidal flats contain more mud, are wetter, and potentially have a higher salinity than other environments. Sediments on active ocean-side beaches are fine sand with a large alongshore variation in gravel-sized shell content. Foredunes behind the beaches consist of dry well-sorted sand.

We have demonstrated that the fully polarimetric multiband synthetic aperture radar (SAR) is able to separate the various subenvinronments and morphological features very well. In general, we have found that C-band is well suited for detailed vegetation discrimination, whereas L- and P-band are better for separating the imagery into larger scale environmental units based on both vegetation and substrate characteristics. Furthermore, L-band appears to best delineate beach ridge and swale morphology. L- and P-band data appear to indicate extensions of tidal creeks cutting across the islands that may not be visible on aerial photography. L- and P-band can also delineate former breaches caused by storms and dredging.

Our statistical classification and modeling of the radar data have focused on delineating the coastal wetland subenvironments. The coastal marshes can be divided into three units: (1) regularly inundated and undifferentiated areas of low marsh and barren tidal flats, (2) regularly inundated low marsh with relatively continuous coverage of vegetation (primarily *Spartina alterniflora*), and (3) irregularly inundated high marsh and transition zones with strongly saline soils. Preliminary statistical classification of the data shows that the marsh subenvironments can be distinctly separated.

We have conducted a preliminary investigation in the use of the radar data to derive soil moisture. Soil moisture is an important parameter for ecological and hydrological modeling, and it varies significantly across the study area. Empirical surface models can be used to describe the surface scattering as a function of soil moisture. However, these models can prove to be inaccurate if significant vegetation is present. We used a SAR-derived criterion to determine whether the vegetation cover in the study area was significant enough to produce inaccurate soil moisture estimates, and we found that it was. As a result, we are now concentrating on physically based discrete scatterer models to explain the AIRSAR return. We have been able to fit the discrete scatter model to the data, but the results of this work are still preliminary.

Plans for Year 2

(1) Our second AIRSAR mission is currently scheduled for June 20 and 21, 1996. During this mission, we will place and survey radar reflectors, reoccupy the topographic survey transects from the first year, and survey additional transects. We will collect more field data including vegetation surveys, sediment samples, and hopefully in situ measurements of the dielectric constant at select locations. We will again operate GPS receivers during the flights to obtain kinematic solutions of the aircraft position.

(2) We will work with JPL in testing the TOPSAR processor using data from Galveston. Once we have the TOPSAR data, we will evaluate the accuracy and resolution of the TOPSAR-derived digital elevation model (DEM) data with ground survey data.

(3) We will continue to use physically based scatterer models to analyze the SAR interactions with wetland terrain and vegetation. We will continue to assess SAR's sensitivity to parameters that are important for the ecological study of wetland ecosystems, such as soil moisture, soil salinity, soil type, and vegetation cover.

(4) We will produce maps of select areas delineating depositional environments, including wetlands, and geomorphic features as derived from the 1995 radar data. Observations made on the ground will aid in developing these maps.

(5) We will combine the 1995 depositional environment maps with the 1995 DEM.

(6) If we receive the 1996 TOPSAR processed data from JPL in time, we will make comparisons with the 1995 data.

Appendix A

Abstract of presentation made at the 1996 Geological Society of America South-Central Section Meeting in Austin, Texas, March 11 to 12.

Citation:

Gibeaut, J. C., Slatton, K. C., Crawford, M. M., and Gutierrez, R., 1996, Mapping depositional environments on barrier islands using airborne synthetic aperture radar: Geological Society of America South-Central Section Meeting, March 11-12, Austin, Texas, Abstracts with Programs, p. 14.

The Bureau of Economic Geology and the Center for Space Research at the University of Texas at Austin are developing techniques to map depositional environments and active and relict geomorphic features on sandy barrier islands and spits using airborne synthetic aperture radar (SAR). Fully polarimetric multiband SAR and C- and L-band topographic SAR data collected by the NASA/JPL airborne system near Galveston, Texas are being analyzed in conjunction with ground measurements and vegetation surveys. One study site on the Bolivar Peninsula barrier spit consists of a relict washover fan/flood-tidal delta complex with marsh and tidal creeks, multiple beach ridges and swales, vegetated barrier flats, foredunes, and beaches. Responses in the radar data corresponding to variations in vegetation, sediment type, and moisture content are visually apparent and allow the mapping of these features. Models are being developed to explain the scattering dependence upon the vegetation, which will in turn yield information about topography, soil salinity, and sediment type. Subsurface variations in soil and sediment composition and geologic structure that appear to be visible in the longer wavelength data are also being investigated.

Appendix B

Abstract submitted to the 1996 International Geoscience and Remote Sensing Symposium to be held May 27 to 31 in Lincoln, Nebraska.

Mapping Geologic Structure on Barrier Islands using Polarimetric SAR

K. Clint Slatton(*), Melba M. Crawford(*), James C. Gibeaut(**), Roberto O. Gutierrez(**)

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The barrier islands along the Texas coast are subject to rapid beach erosion and accretion, land subsidence, and frequent tropical storms whose surface scars often persist for years. Surface character in this extremely low-relief (<10 ft) coastal zone is very sensitive to these dynamic processes which manifest themselves geologically as beach ridges, storm scarps, and variations in soil types. Both surficial and subsurface structure potentially yield information about the occurrence of specific historical events and the continuous geologic evolution of the area. Correct interpretation of the geologic history of the area as well as mapping and understanding the ongoing processes is critical for determining appropriate management strategies for this ecologically critical region.

Fully polarimetric multiband AIRSAR and C- and L-band TOPSAR collected by the NASA/JPL airborne system near Galveston, Texas are being analyzed in conjunction with ground measurements and vegetation surveys. One study site on Bolivar Peninsula consists of a coastal wetland region (saltwater marsh), which has been partially overlaid by fore-island dunes and vegetated barrier flats through peninsula accretion. As a result salinity and soil type vary significantly throughout the area, i.e. the wetland soils have high percentages of clay, while the dunes and barrier flats are comprised mainly of loose sandy soils. Responses in the radar data corresponding to these variations are visually apparent. Models are being developed to explain the backscatter dependence upon these soil properties. Subsurface variations in soil composition and geologic structure that appear to be visible in the longer-wavelength data are also being investigated. The existence of storm relicts and submerged structure will be validated from historical aerial photographs and field corings.

Appendix C

Abstract submitted to the 1996 American Geophysical Union Spring Meeting to be held May 20 to 24 in Baltimore, Maryland.

Geomorphic Analysis and Depositional Environment Mapping of Barrier Island Systems Using AIRSAR

Gibeaut, J. C., Slatton, K. C., Crawford, M. M., Gutierrez, R. G., and White, W. A.

Low-relief (less than 4 m) barrier islands and spits change on a variety of spatial and temporal scales. Tropical storms cause rapid and large changes in morphology, sediment distribution, and vegetation. Seasonal storms and fair-weather periods cause smaller, quasi-periodic change, whereas relative sea-level variation and changing sediment supplies cause large, long-term change. To better understand these dynamic systems, we are developing techniques to map depositional environments, vegetation, and active and relict geomorphic features using synthetic aperture radar (SAR). Polarimetric multiband SAR and C- and L-band topographic SAR collected by the NASA/JPL airborne system near Galveston, Texas, are being analyzed in conjunction with ground measurements and vegetation surveys.

The study area on Galveston Island and Bolivar Peninsula consist of multiple beach ridges and swales, vegetated barrier flats, foredunes, high- and low-saltwater marshes, intertidal/wind-tidal flats, tidal creeks, tidal deltas, and exposed and sheltered beaches. Also present are relict washover fan/flood-tidal delta complexes. Salinity, vegetation, sediment/soil type, and surface roughness vary significantly between these areas. Beach ridges have dry, shelly sand sediment, and intervening swales between ridges are wetter with some having standing water. Barrier flats are also made of shelly sand and support land uses such as agriculture, ranching, and urban/recreational development. Sediments forming saltwater marshes and intertidal/wind-tidal flats contain more mud, are wetter and potentially have a higher salinity than other environments. Sediments on active ocean-side beaches are fine sand with a large alongshsore variation in gravel-sized shell content. Foredunes behind the beaches consist of dry well-sorted sand.

Responses in C-, L-, and P-band SAR data corresponding to the above variations are visually apparent. L-band appears to best delineate beach ridge and swale morphology. L- and P-band data appear to indicate extensions of tidal creeks cutting across the islands that may not be visible on aerial photography. L- and P-band can also delineate former breaches caused by storms and dredging. C-band provides the greatest detail related to vegetation. Together with ground measurements, the SAR data are being used to develop models explaining C- and L-band scattering for the various types of vegetation and terrain.

Appendix D

Manuscript submitted to the 1996 International Geoscience and Remote Sensing Symposium to be held May 27 to 31 in Lincoln, Nebraska.

Modeling Wetland Vegetation Using Polarimetric SAR

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Abstract -- Airborne polarimetric Synthetic Aperture Radar (SAR) data are investigated for their potential in mapping herbaceous coastal wetlands. The subenvironments of coastal wetlands have very distinct vegetation cover and surface properties. Qualitative analysis of the SAR images reveals the relative importance of surface and vegetation scatter in these subenvironments. Furthermore, sampled SAR data distinctly separate the subenvironments, indicating that classification techniques could be used to discriminate among them. Although wetland environments are typically too vegetated to use empirical surface models to explain the SAR return, discrete scatterer models can be used to account for the scattering due to the vegetation. A discrete scatterer model fitted to a coastal wetland site on Bolivar Peninsula near Galveston, Texas provides insight into the dominant scattering mechanisms, and may aid in the accurate mapping of coastal wetlands.

INTRODUCTION

Modeling the scatter of microwave radiation by natural surfaces and vegetation is important for assessing the ability of radar remote sensing to accurately map terrain and land cover. Coastal wetlands comprise a critical ecosystem for specialized vegetation and wildlife habitats, as well as for the natural production of methane. The Synthetic Aperture Radar (SAR) backscatter coefficient (σ^0) is a complex function of local characteristics including topography, geological composition, soil moisture and salinity, and vegetation density and structure. Modeling the scatter from the vegetation is important for classifying land cover, monitoring change in dynamic environments, and discriminating among mechanisms of the backscattered return. The focus of this work is the analysis and modeling of the SAR return from coastal wetland vegetation. Both fully polarimetric SAR data in C, L, and P bands and fixed-baseline interferometric SAR (TOPSAR) data were acquired by the NASA/JPL AIRSAR system in April 1995. The data were acquired in support of a project to detect topographic change and relict geomorphic features on barrier islands for NASA's Topography and Surface Change Program. Imagery over a salt marsh is being used for a preliminary study of the effects of vegetation on the SAR return.

Interest in SAR response to wetland environments has increased in recent years. Ormsby and Blanchard [1] studied the effect of inundation on σ^0. Pope et al. [2] developed wavelength and polarization dependent indices of σ^0 which represent scattering mechanisms such as attenuation due to vegetation and depolarization due to vegetation multiple scattering. Such indices can be used as qualitative measures of the effect of vegetation cover on the total σ^0 return.

Understanding the scatter due to vegetation also helps relate the σ^0 return to surface properties such as soil moisture. Knowledge of the soil moisture distribution can then be used as an input for hydrological models. SAR's value in retrieving soil moisture estimates from barren and sparsely vegetated areas has been shown by Dubois et al., [3] and others. Typically, surface models that relate σ^0 to soil moisture are empirically derived for specific data sets. These models have difficulty separating the return due to soil moisture from the scatter due to surface roughness and vegetation multiple scatter. If the scattering due to vegetation could be well characterized, its effects might be accounted for, allowing for the estimation of soil moisture over vegetated areas.

Models that represent vegetation as a layer of discrete scattering elements have been developed to characterize the scatter due to vegetation. Most of this research has focused on forested areas, but some work has been done for herbaceous vegetation. Saatchi et al. [4] developed a model for grass canopies, and Durden et al. [5] modeled scatter from inundated rice fields. The model developed by Lang and Sidhu [6] was used to study the SAR return from a coastal wetland test site. Before such a model is fit to the data, the σ^0 values are often plotted versus incidence angle. These plots can be used to fit the model to the data, and to determine how well SAR is able to separate different environments. In this study, a variety of methods were used to study the SAR response to coastal wetlands, including visual interpretation, empirical surface modeling, and discrete scatterer modeling. Some preliminary observations from each method are discussed.

SITE DESCRIPTION

The test site is located on Bolivar Peninsula, Texas, shown in Fig. 1, and consists of an herbaceous salt marsh, vegetated upland flats, and an intermediate transition zone, shown in Fig. 2. The SAR scene contains a typical transition from a salt marsh to vegetated upland flats. This transition involves four subenvironments: a low salt marsh with barren tidal flats that is flooded often; a low salt marsh with nearly continuous vegetation cover that is less frequently flooded; a transition zone with occasional seawater

This work was supported by the National Aeronautics and Space Administration, under the Topography and Surface Change Program (Grant NAG5-2954).

flooding; and the vegetated upland flats. The entire peninsula is extremely low relief (<4 m), so even small changes in elevation can produce significant changes in the soil moisture and salinity. The peninsula is a sandy barrier spit formed during the last 4,000 years, primarily through spit accretion, and modified by washover and tidal inlet processes.

Because the uplands are higher in elevation and contain sandy soils, they are well drained and non-saline. The tidal-flat low marsh contains muddy (silt + clay) soils with high concentrations of organic material. It is flooded almost daily with seawater. The continuous-cover low marsh soils are similar to those found in the tidal-flat low marsh, but contain less organic material. The transition zone corresponds to the mean high water mark. Because of evaporation between seawater inundations, this area is extremely saline.

These variations in ground conditions give rise to variations in the vegetation cover. In the tidal-flat low marsh, tall grasses grow to heights of 2 m [7]. These grasses often occur in small groups intermixed with the barren tidal flats. The continuous-cover low marsh also contains tall grasses (< 1.5 m), but the plants are more consolidated creating a more uniform cover. Due to the high saline concentration in the transition zone, that area contains many barren salt flats, and supports mainly small succulent plants. The uplands have a drier, rougher surface, and support short (< 0.5 m) range grasses.

The variations in vegetation , soil type, soil moisture, and soil salinity all involve variations in electrical and geometric properties to which SAR is sensitive. It was therefore expected that SAR would be useful for mapping herbaceous wetlands.

ANALYSIS

Initial analysis of the SAR images consisted of visual interpretation. C-band showed subtle variations in vegetation, but was so strongly scattered by all vegetation that the subenvironments were not well delineated. The longer wavelength L- and P-band separated the four subenvironments very well.

Because of the extremely low relief, local slope changes were assumed to be unimportant in the σ^0 return. Several σ^0 indices were examined to qualitatively determine the relative importance of surface scatter and vegetation multiple scatter in the four subenvironments. The "canopy structure index" (csi) [2] was used as a measure of the vertical co-polarized return relative to the sum of the vertical and horizontal co-polarized returns. The csi reveals variations in the predominant orientation of vegetation structure. Because attenuation of σ^0_{vv} can be much greater than attenuation of σ^0_{hh} at P-band [8], the csi was also expected to reveal attenuation due to vegetation. As expected, the P-band csi image showed that most attenuation occurred in the dense vegetation of the continuous-cover low marsh. The tidal-flat low marsh produced less attenuation due to the lack of continuous vegetation cover. The transition zone showed the least attenuation.

A "volume scattering index" (vsi) was adapted from [2] and used as a measure of the depolarization relative to the sum of the co-polarized and cross-polarized returns. At L-band, the uplands exhibited the most volume scattering, while the continuous-cover low marsh exhibited the most volume scattering at P-band. It was therefore concluded that P-band was achieving some penetration of the upland vegetation. From the qualitative analysis of these indices, it appeared that there were scattering contributions from both the surface and vegetation in the uplands, the return from the transition zone was almost entirely due to surface scatter, the continuous-cover low marsh returns were mostly due to strong vegetation scatter, and the weaker returns from the tidal-flat low marsh were due to specular reflection off of the water surface.

In an effort to retrieve soil moisture estimates, empirical surface models were studied. Before any of these models could be applied, it was necessary to assess how the presence of the vegetation cover would affect the soil moisture estimates. The criterion developed in [3] was used to determine whether the vegetation cover over the test site was thick enough to reduce the accuracy of such models. That criterion consisted of the ratio $\sigma^0_{hv} / \sigma^0_{vv}$ at L-band. If this ratio is greater than -11 dB, the model is not recommended for estimating soil moisture. This criterion was exceeded over most of the Bolivar SAR image. Empirical surface models were therefore abandoned in favor of discrete scattering models.

In addition to the techniques mentioned above, σ^0 data were sampled from the four subenvironments and plotted versus radar incidence angle. Fig. 3 shows one such plot for L-band. These plots clearly demonstrated polarimetric SAR's ability to separate the subenvironments and its potential for herbaceous wetland mapping. Strong σ^0_{hh}, due mostly to vegetation multiple scatter at L-band, occurs in the uplands. A marked decrease in σ^0_{hh} over the transition zone is due to that region's lack of vegetation and extremely smooth surface. The continuous-cover low marsh possesses strong σ^0_{hh} due to vegetation scatter. The decrease in σ^0_{hh} over the tidal-flat low marsh is due to specular reflection off of the water surface and is evidence of inundation. Using all available bands and polarizations should provide ample discriminators for the classification of these subenvironments.

The discrete scatterer model developed by Lang and Sidhu [6] was fitted to these data to gain insight into the scattering mechanisms in each subenvironment. The model represents the vegetation cover as a layer of discrete scattering elements over a flat half space. The lower half space was assumed to be saline water for the inundated tidal-flat low marsh [5], and soil for the other subenvironments. A soil dielectric mixing model adapted from [9] was used to compute the soil dielectric constant. The total σ^0 is computed as the sum of the σ^0 due to (i) direct scatter from the vegetation, (ii) scatter from a single-reflection ground/vegetation interaction, and (iii) scatter from a double-reflection ground/vegetation interaction. Preliminary attempts to fit the scattering model to the data have been successful, but are difficult to interpret because there are insufficient ground data to properly constrain the model. Additional ground truth will be collected so that the model may be quantitatively applied to the data.

SUMMARY AND FUTURE WORK

It is clear that polarimetric multiband SAR has potential for mapping the major subenvironments associated with coastal herbaceous wetlands. A discrete scatterer model can be fitted to the data to gain insight into the scattering mechanisms that occur.

Additional ground data, such as soil and plant dielectric constants, will be collected to constrain the scattering model. Also, the effects of direct surface scattering will be included in the model to account for sparsely vegetated areas.

REFERENCES

[1] Ormsby, J. P., and B. J. Blanchard, "Detection of Lowland Flooding Using Active Microwave Systems," Photogrammetric Engr. and Remote Sensing, vol. 51, no. 3, pp. 317-328, 1985.

[2] Pope, K. O., J. M. Reybenayas, and J. F. Paris, "Radar Remote Sensing of Forest and Wetland Ecosystems in the Central American Tropics," Remote Sensing Environ., vol. 48, pp. 205-219, 1994.

[3] Dubois, P. C., J. J. van Zyl, and T. Engman, "Measuring Soil Moisture with Imaging Radars," IEEE Trans. Geosci. Remote Sensing, vol. 33, no. 4, pp. 915-926, 1995.

[4] Saatchi, S. S., D. M. Le Vine, R. H. Lang, "Microwave Backscattering and Emission Model for Grass Canopies," IEEE Trans. Geosci. Remote Sensing, vol. 32, no. 1, pp. 177-186, 1994.

[5] Durden, S. L., L. A. Morrissey, and G. P. Livingston, "Microwave Backscatter and Attenuation Dependence on Leaf Area Index for Flooded Rice Fields," IEEE Trans. Geosci. Remote Sensing, vol. 33, no. 3, pp. 807-810, 1995.

[6] Lang, R. H. and J. S. Sidhu, "Electromagnetic Backscattering From a Layer of Vegetation: A Discrete Approach," IEEE Trans. Geosci. Remote Sensing, vol. GE-21, no. 1, pp. 62-71, 1983.

[7] Webb, J. W., Typical Dune Vegetation of the Upper Texas Coast, non-published Texas A&M at Galveston document, pp. iii, 3.

[8] Le Vine, D. M., and M. A. Karam, "Dependence of Attenuation in a Vegetation Canopy on Frequency and Plant Water Content," in Proc. IGARSS'95, vol. I, pp. 607-609, 1995.

[9] Ulaby, F. T., A. K. Moore, A. K. Fung, Microwave Remote Sensing, Active and Passive, vol. 3, Artech House, pp. 2086-2103, 1986.

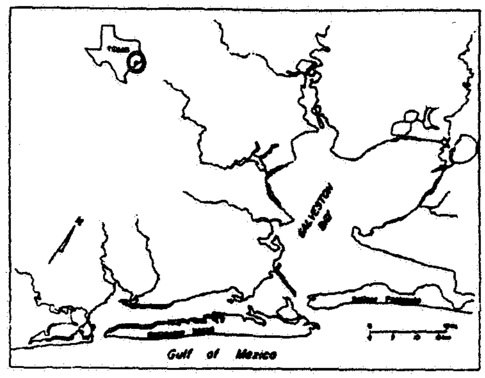

Fig. 1: Study area.

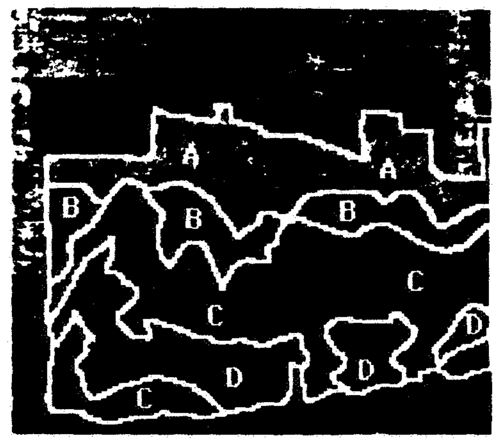

Fig. 2: L-band image of test site with subenvironments labeled as (A) vegetated upland flats, (B) transition zone, (C) continuous-cover low marsh, and (D) tidal-flat low marsh.

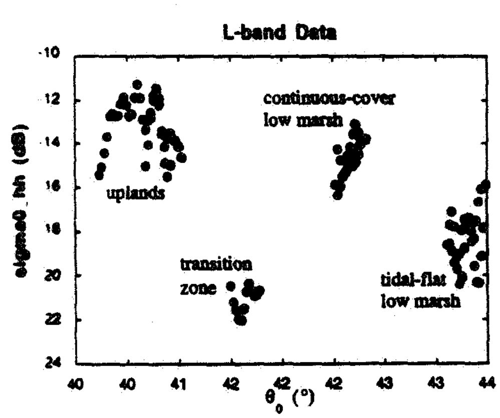

Fig. 3: L-band σ^0_{hh} values versus incidence angle for the four subenvironments.